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UPDATING THE NRC'S GUIDANCE FOR HUMAN FACTORS ENGINEERING REVIEWS

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Updating the NRC's Guidance for Human Factors Engineering Reviews

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Abstract - **The U.S. Nuclear Regulatory Commission (NRC) reviews the human factors engineering (HFE) aspects of nuclear plants. NUREG-0800 (Standard Review Plan), Chapter 18, "Human Factors Engineering," is the principal NRC staff guidance document. Two main documents provide the review criteria to support the evaluations. The *HFE Program Review Model* (NUREG-0711) addresses the design process from planning to verification and validation to design implementation. The *Human-System Interface Design Review Guidelines* (NUREG-0700) provides the guidelines for the review of the HFE aspects of human-system interface technology, such as alarms, information systems, controls, and control room design. Since these documents were published in 1994 and 1996 respectively, they have been used by NRC staff, contractors, nuclear industry organizations, as well as by numerous organizations outside the nuclear industry. Using feedback from users and NRC research conducted in recent years, both documents have been revised and updated. This was done to ensure that they remain state-of-the-art evaluation tools for changing nuclear industry issues and emerging technologies. This paper describes the methodology used to revise and update the documents and summarizes the changes made to each and their current contents.**

Index Terms **- Control system human factors, Ergonomics, Human factors, Nuclear power generation safety.**

I. BACKGROUND

Nuclear power plant (NPP) personnel play a vital role in the productive, efficient, and safe generation of electric power. Operators monitor and control plant systems and components to ensure their proper operation. Test and maintenance personnel help ensure that plant equipment is functioning properly and restore components when malfunctions occur. The importance of the human factors engineering (HFE) aspects of NPP design to personnel performance, and both reliable and safe plant operation, is widely acknowledged.

The U.S. Nuclear Regulatory Commission (NRC) reviews the HFE aspects of NPPs to ensure that personnel performance and reliability are appropriately supported. The main NRC guidance for these reviews is contained in three documents: NUREGs-0800, 0711, and 0700. The *Standard Review Plan* (NUREG-0800) provides a high-level review framework for the conduct of HFE reviews [1]. NUREG-0800 references the *HFE Program Review Model* (NUREG-0711) for detailed review criteria [2].

NUREG-0711, Rev. 0 was originally developed to support reviews of advanced reactor design certification applications. Its focus was on the design process in addition to the design product. It was needed for two reasons. First, the existing guidance at that time did not address the technological approaches employed in the advanced reactor designs. Second, the existing guidance was oriented toward the review of an existing control room, yet at the time the NRC had to perform the design certification reviews, the control rooms were not yet built; in fact, even the designs for many control rooms were incomplete.

While NUREG-0711, Rev. 0 provides review criteria for the design process, it references the *Human-System Interface Design Review Guideline* (NUREG-0700, Rev. 1) [3] for detailed review criteria for human-system interface (HSI) design, including alarms, displays, procedures, support systems, and controls.

NUREG-0711, Rev. 0 was revised to incorporate the results of design process work and to take advantage of lessons learned in using the guidance for three advanced reactor reviews and in numerous other applications. In addition, it is being revised to serve its broader role as general HFE review guidance as dictated in NUREG-0800 (i.e., not limited to advanced reactor reviews). The revision of NUREG-0700, Rev. 1 addressed the "gaps" in the criteria. Since the publication of NUREG-0700,

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Rev. 1, the NRC has conducted the needed research and has made sufficient progress to support a second revision.

An overview of the methodology used to revise these documents is provided in Section II. A brief summary of the changes to each is provided in Section III.

II. GUIDANCE DEVELOPMENT METHODOLOGY

When the effort to update NUREGs-0711 and -0700 began, a methodology was established for new guidance development that would provide a useful synthesis of knowledge. The method development was guided by the objective to establish a process that (1) results in valid, technically defensible, HFE guidance, (2) can be applied to any aspect of HFE technology for which review guidance is needed, and (3) optimally uses available resources, i.e., is cost effective.

The methodology emphasizes establishing the validity of the guidelines. Validity is defined along two dimensions: internal and external. *Internal validity* is the degree to which the individual guidelines are linked to a clear, well-founded, and traceable technical basis. The technical basis is the information upon which the guideline is established and justified. The technical bases vary for individual HFE guidelines. Some guidelines may be based on technical conclusions from an analysis of empirical research, some on a consensus of existing standards, while others are based on engineering judgment that a guideline represents sound practices based on the information reviewed. Maintaining an audit trail from the guidelines to their technical basis allows: (1) the technical merit of the guideline to be evaluate-d by others; (2) a more informed application of the guideline since its basis is available to users; and (3) deviations or exceptions to the guideline to be evaluated.

External validity is the degree to which the guidelines are supported by independent peer review. Peer review is a good method of screening guidelines for conformance to generally accepted HFE practices and to industry-specific considerations, i.e., for ensuring that the guidelines are appropriate based on practical operational experience with the use of HSIs in actual systems.

For individual guidelines, these forms of validity can be inherited from the source documents that form their technical basis. For example, many HFE standards and guidance documents were developed with good internal and external validity. However, when validity is not inherited from the source documents, it must be established as part of the guidance development process. Our guidance development methodology was established to provide internal validity based on a documented technical basis and external validity based on the test, evaluation, and peer review of the guidance.

The methodology is divided into the following steps: A - Characterization of the Topic; B- Development of the Technical Basis; C- Development and Documentation of HFE Guidelines; D- Test, Evaluation, and Peer/Industry Review of Guidance; and E - Final Guidance Publication.

A. Characterization of the Topic

The first step in developing guidance for a topic, such as computer-based procedures, was a needs analysis, i.e., the identification of the areas for which guidance is needed. To accomplish this, we reviewed existing systems and identified the characteristics and functions that constitute the dimensions along which the topic can be defined. The characterization is important because it provided a structure for developing and organizing the guidance.

B. Development of the Technical Basis

Before guidelines can be developed, the technical information on which guidance will be based must be established. Several sources of information were used for guidance development. We first considered existing HFE standards and guidance documents. The developers of these documents considered the available research and operational experience, and using their knowledge and expertise, developed HFE guidelines. In addition, most of them have been peer reviewed. Thus, the documents have internal validity, external validity, or both. Further, since the information was already in guideline form, it was generally easier to use. While such documents provide a technically valuable starting place, there are often many aspects of a topic that extend beyond the technology and human performance considerations addressed by these documents. Thus additional sources of information were utilized.

We next sought documents providing good syntheses of existing literature, such as handbooks and texts. These documents are valuable in that they generally review research and operational literature and are design oriented. However, the information is usually not expressed in guidance form. Guidance needs to be developed from these documents, but the establishment of a technical basis is usually expedited by the information reviewed.

For issues reflecting new technology, frequently the sources discussed above are not sufficient to support guidance development. Then, basic literature was reviewed. This literature consists mainly of papers from research journals and technical conferences. Basic literature provides a theoretical basis for understanding human performance concerns related to complex human-machine systems. It also provides general theory for human-machine interaction relevant to user interface design, human error, and usability. Empirical studies of human-machine interaction reported in the literature address a broad range of technologies and user tasks. However, greater effort is needed to develop such information into design guidance. Engineering judgment is required to consider the applicability of these empirical studies to NPP operations. This is because individual studies tend to have unique constraints that may limit their generalizability (such as their unique

participants, types of tasks performed, and types of equipment used). For example, laboratory experiments often do not involve tasks of the complexity of NPP operations, and most experiments do not examine tasks under the same performance shaping factors (such as rotating shifts, stress, and fatigue) that exist in a work environment. Thus, the results were interpreted in the context of real-world tasks and systems, which involved judgment based on professional and operational experience.

Another source is industry experience, which includes reports and surveys of plant personnel and designers, as well as incident reports that provide information relevant to the HFE topic for which guidance is being prepared. Operational experience was also obtained from interviews, knowledge-elicitation sessions, and walk-through exercises using the actual HSI or a high-fidelity training simulator. Industry practices include design approaches that have evolved through experience. This information was more directly relevant to the NPP domain than basic literature.

Finally, where the above sources were insufficient, original research was performed. Original research has the advantage of providing focus on the specific issues that need to be addressed in guidance development. However, because of the time and resources required to conduct original research, it was only used when important information could not be obtained through other means. Several such studies were performed [4-6].

C. Development and Documentation of HFE Guidelines

Once the technical information was assembled, a set of guidelines was developed from the source materials. The guidelines were organized in a standard format. A database is used to link guidelines with their technical basis and to track changes and modifications that are made as a result of the review and feedback process.

Where there was insufficient information to provide a technical basis from which to develop valid design guidance, an issue was defined. From a research standpoint, issues reflect topics that will require additional investigation to resolve. From a design review standpoint, issues reflect aspects of design that have to be addressed on a case-by-case basis, e.g., using design-specific tests and evaluations.

The guidelines, issues, and the guidance development methodology for each HFE topic were documented in technical reports. These reports are listed in the references [6 to 17].

D. Test, Evaluation, and Peer/Industry Review of Guidance

A questionnaire on the use of NUREG-0711 and -0700 was distributed to the world-wide community of users. The purpose of the questionnaire was to obtain feedback on aspects of the documents that needed improvement. These evaluations provided much good information that contributed to the development of the revisions.

Many of the individual technical reports were reviewed by the Electric Power Research Institute, the Crew Systems Ergonomics Information Analysis Center, and the Institute of Electrical and Electronics Engineers (IEEE). These reviews included evaluations of the topic characterizations and the guidance. The guidance evaluation included its scope, comprehensiveness, technical content, technical basis (adequacy of its internal validity), and usability (i.e., presentation, functionality, and procedures). Comments from the peer reviews were used to revise the guidance.

E. Final Guidance Publication

The draft guidance was then revised and integrated into the revised versions of NUREGs -0711 [18] and -0700 [19]. The set of technical reports remains as the documentation of the basis for the guidance [6 to 17].

III. DESCRIPTION OF THE REVISED DOCUMENTS

A. NUREG-0711, Rev. 1

The main changes to NUREG-0711 are summarized in this section. First, all of the design review process and procedural information from NUREG-0700 was integrated into NUREG-0711, Rev. 1. This provides a clear distinction between the two documents: all process material is in NUREG-0711, Rev. 1 and NUREG-0700, Rev. 2 contains only guidelines for HSI reviews.

Second, while NUREG-0711, Rev. 0 addressed new control room designs, the NUREG-0711, Rev. 1 addresses control room modernization issues as well. In addition, two new sections were added, thus expanding the number of review elements from 10 to 12. The new elements are Design Implementation and Human Performance Monitoring. Design Implementation addresses the manner in which changes are made to control rooms and other HSIs. The guidance focuses on review of the implementation of plant changes so the effects on personnel performance are considered. Human Performance Monitoring provides guidance to assure that a human performance monitoring strategy is in place so that no significant safety degradation occurs because of any changes that are made in the plant and to provide adequate assurance that the conclusions that have been drawn from the evaluation remain valid over time.

The elements that have changed significantly include:

- Functional Requirements Analysis and Allocation. The central focus was shifted to the importance of "role of the operator" and the criteria were simplified to better reflect the evolutionary nature of changes in the industry.

- Human Reliability Analysis. Section 7.4.1, Human Reliability Analysis Methodology was eliminated and

an abbreviated form of the material was included as part of the introductory discussion.

- Human-System Interface Design. The criteria were replaced with the criteria from the BNL Technical Report on HSI design [16].

- Human Factors Verification and Validation. The criteria were significantly expanded by integrating the design review procedures from NUREG-0700, Rev. 1, Part 1 into this element and replacing the criteria for integrated system validation with those from NUREG/CR-6393 [15].

B. NUREG-0700, Rev. 2

NUREG-0700, Rev. 2 has changed considerably from Rev. 1. As noted above, all of the review procedures have been removed and integrated with NUREG-0711. A summary of the changes to the guidelines is presented below.

HSI characterizations have been added to each major section. A characterization is a description of the characteristics and functions of the HSI topic area that are important to human performance. The characterizations provide a conceptual framework for indicating the specific aspects of the HSI design for which information should be obtained and reviewed. The characterizations are sometimes broader in scope than the HFE guidelines themselves. This exists when a particular aspect of a topic was identified as important to human performance, but there was not a sufficient technical basis upon which to develop detailed design review guidelines.

New guidance was developed to addresses the following aspects of HSI design:

- Information Design and Organization
- Group View Displays
- Interface Management and Navigation
- Soft Controls
- Computer-Based Procedures
- Alarm Systems
- Control Room and Work Place Environment
- Digital System Maintenance

This led to a reorganization of the guidance. The HFE guidelines are organized into four basic parts, which are divided into sections. Part I contains guidelines for the basic HSI elements: information display, user-interface interaction and management, and controls. These elements are used as building blocks to develop HSI systems to serve specific functions. The guidelines address the following aspects of these HSI elements:

- Information Display. This section provides HFE guidelines for the review of visual displays. Following a section of general guidelines, guidelines are provided in top-down fashion, beginning with display formats (such as mimic displays and trend graphs), display format elements (such as labels, icons, symbols, color, text, and coding), data quality and update rate, and display devices (such as video display terminals and large board displays).

- User-Interface Interaction and Management. This section provides HFE guidelines for the review of the modes of interaction between plant personnel and the HSI. Topics include dialogue formats (such as menus, direct manipulation, and command language), navigation, display controls, entering information, system messages, and prompts. This section also contains guidelines concerning methods for ensuring the integrity of data accessed through the user interface. Guidelines cover prevention of inadvertent change or deletion of data, minimization of data loss due to computer failure, and protection of data, such as set points, from unauthorized access.

- Controls. This section provides HFE guidelines for the review of information entry, dialogue types, display control, information manipulation, and system response time. Review guidelines are also provided for conventional control devices such as pushbuttons and various types of rotary controls. Considerations of display-control integration are also included here.

Part II contains the guidelines for reviewing seven systems: alarm system, safety function and parameter monitoring system, group-view display system, soft control system, computer-based procedure system, computerized operator support system, and communication system. The guidelines include the functional aspects of the system, as well as any unique considerations for display, user-system interaction, and control that may be needed to review the system. The guidelines address the following aspects of these HSI systems:

- Alarm System. This section provides HFE guidelines for the review of alarm system design implementation. The guidelines address the selection of alarm conditions, choice of set points, alarm processing, alarm availability (such as filtering and suppression of alarms), unique aspects of the display of alarm information (such as organization, coding, and alarm message content), and alarm controls.

- Safety Function and Parameter Monitoring System. This section provides HFE guidelines for the review of displays of critical safety functions and safety parameters.

- Group-View Display System. This section provides HFE guidelines for the review of group-view displays, including their functional characteristics and user-system interaction aspects, as well as their physical characteristics.

- Soft Control System. This section provides HFE guidelines for the review of the information display and user-system interaction aspects of soft control systems.

- Computer-Based Procedure System. This section provides HFE guidelines for the review of computer-based procedure systems, including the representation of information, the functional capabilities, users' interaction with the systems, backup provisions, and the integration of such system with other HSI elements.

- Computerized Operator Support System. This section provides HFE guidelines for the review of the aids provided to personnel for situation analysis and decision making. Guidelines are provided that address functional requirements such as explanation and simulation facilities, and the desirable characteristics of their user interfaces.

- Communication System. This section provides HFE guidelines for the review of speech and computer-mediated communication between plant personnel, e.g., preparing, addressing, transmitting, and receiving messages.

Part III provides guidelines for the review of workstations and workplaces. Workstations, including consoles and panels, are locations where HSIs are integrated together to provide an area where plant personnel can perform their tasks. Workstations are located at workplaces, such as the main control room and remote shutdown facilities. The guidelines address the following:

- Workstation Design. This section provides HFE guidelines for the review of the design of workstation features such as control-display integration and layout, labeling, and ergonomics, e.g., vision and reach.

- Workplace Design. This section provides HFE guidelines for the review of general workplace considerations. Guidelines are provided both for the control room and for operator interface areas out in the plant. The guidelines address design features such as the overall layout of the workstations within the workplace and other equipment such as group-view displays within the workplace, provision of support equipment such as ladders or tools, and environmental characteristics including temperature, ventilation, illumination, and noise.

Part IV provides guidelines for the review of HSI support, i.e., maintaining digital systems.

Finally, guidance for HSI-specific HFE design process considerations for information display, computer-based procedures, and interface management are included. This guidance addresses human performance issues associated with an HSI technology that must be reviewed on a case-by-case basis because the technical basis does not support HFE guidance development.

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